

**FIBER-OPTIC CHANNEL SELECTING APPARATUS****FIELD OF THE INVENTION**

5 The present invention relates generally to the coupling of selected input and output lines  
or channels through which optical signals are directed, and to the routing of optical signals to  
and from such lines or channels. More specifically, the present invention relates to the design  
and use of a device adapted to effect selection and coupling through coordinated mechanical  
indexing movements and/or the use of optical fiber bundles whose ends are exposed to a  
detector. Such a device provides advantage in a wide variety of fields of application, particularly  
10 in applications involving the generation and transmission of analytical information. Specific  
fields of use include the preparation, sampling and analyzing of soluble materials as well as the  
testing of other fluids and solid materials exhibiting optical characteristics.

**BACKGROUND OF THE INVENTION**

15 Optical transport techniques are often utilized to direct a beam or pulse of light from a  
light source to a test site and, subsequently, to carry analytical information generated or  
measured at the test site to a suitable light receiving device. Analytical information transmitted  
by optical means can be chemical or biological in nature. For example, the analytical  
information can be used to identify a particular analyte, i.e., a component of interest, that is  
20 resident within the sample contained at the test site and to determine the concentration of the  
analyte. Examples of analytical signals include, among others, emission, absorption, scattering,  
refraction, and diffraction of electromagnetic radiation over differing ranges of spectra. Many of  
these analytical signals are measured through spectroscopic techniques. Spectroscopy generally  
involves irradiating a sample with some form of electromagnetic radiation (i.e., light), measuring  
25 an ensuing consequence of the irradiation (e.g., absorption, emission, or scattering), and  
interpreting of the measured parameters to provide the desired information. An example of an  
instrumental method of spectroscopy entails the operation of a spectrophotometer, in which a  
light source in combination with the irradiated sample serves as the analytical signal generator  
and the analytical signal is generated in the form of an attenuated light beam. The attenuated  
30 signal is received by a suitable input transducer such as a photocell. The transduced signal, such  
as electrical current, is then sent to a readout device.

As one example for implementing spectral analysis, a spectrophotometer uses ultraviolet  
(UV) and/or visible light, or in other cases infrared (IR) or near infrared (NIR) light, to scan the

sample and calculate absorbance values. In one specific method involving the UV or UV-visible spectrophotometer, the UV sipper method, the sample is transferred to a sample cell contained within the spectrophotometer, is scanned while residing in the sample cell, and preferably is then returned to the test vessel.

- 5           The concentration of a given analyte in a sample through spectrochemical determination typically involves several steps. These steps can include (1) acquiring an initial sample; (2) performing sample preparation and/or treatment to produce the analytical sample; (3) using a sample introduction system to present the analytical sample to the sample holding portion of a selected analytical instrument (e.g., transferring the sample to the sample-holding portion of a
- 10   UV spectrophotometer); (4) measuring an analytical signal (e.g., an optical signal) derived from the analytical sample; (5) establishing a calibration function through the use of standards and calculations; (6) interpreting the analytical signal based on sample and reference measurements; and (7) feeding the interpreted signal to a readout and/or recording system.

Conventional equipment employed in carrying out the above processes are generally

15   known in various forms. Measurement of the analytical signal involves employing a suitable spectrochemical encoding system to encode the chemical information associated with the sample, such as concentration, in the form of an optical signal. In spectrochemical systems, the encoding process entails passing a beam of light through the sample under controlled conditions, in which case the desired chemical information is encoded as the magnitude of optical signals at

20   particular wavelengths. Measurement and encoding can occur in or at sample cells, cuvettes, tanks, pipes, solid sample holders, or flow cells of various designs.

In addition, a suitable optical information selector is typically used to sort out or discriminate the desired optical signal from the several potentially interfering signals produced by the encoding process. For instance, a wavelength selector can be used to discriminate on the

25   basis of wavelength, or optical frequency. A radiation transducer or photodetector is then activated to convert the optical signal into a corresponding electrical signal suitable for processing by the electronic circuitry normally integrated into the analytical equipment. A readout device provides human-readable numerical data, the values of which are proportional to the processed electrical signals.

- 30           For spectrophotometers operating according to UV-visible molecular absorption methods, the quantity measured from a sample is the magnitude of the radiant power or flux supplied from a radiation source that is absorbed by the analyte species of the sample. Ideally, a value for the absorbance  $A$  can be validly calculated from Beer's law:

$$A = -\log T = -\log \frac{P}{P_0} = abc,$$

where  $T$  is the transmittance,  $P_0$  is the magnitude of the radiant power incident on the sample,  $P$  is the magnitude of the diminished (or attenuated) radiant power transmitted from the sample,  $a$  is the absorptivity,  $b$  is the pathlength of absorption, and  $c$  is the concentration of the absorbing species.

It thus can be seen that under suitable conditions, absorbance is directly proportional to analyte concentration through Beer's law. The concentration of the analyte can be determined from the absorbance value, which in turn is calculated from the ratio of measured radiation transmitted and measured radiation incident. In addition, a true absorbance value can be obtained by measuring a reference or blank media sample and taking the ratio of the radiant power transmitted through the analyte sample to that transmitted through the blank sample.

In some types of conventional sample testing systems, samples are transferred sequentially to one or more sample cells that are contained within the analytical instrument (e.g., spectrophotometer) itself. Samples are first taken from test vessels and, using sampling pumps, carried over sampling lines and through sampling filters. The samples are then transported to a UV analyzer, an HPLC system, a fraction collector, or the like. The analytical instrument may include a carousel that holds several sample cuvettes, such that rotation of the carousel brings each cuvette into position at the sample cell in a step-wise manner. The pulsing of the light source supplying the initial optical signal can be synchronized by control means with the rotation of the carousel.

Examples of UV-vis spectrophotometers are those available from Varian, Inc., Palo Alto, California, and designated as the CARY™ Series systems. In particular, the Varian CARY 50™ spectrophotometer includes a sample compartment that contains a sample cell through which a light beam or pulse passes. Several sizes of sample cells are available. In addition, the spectrophotometer can be equipped with a multi-cell holder that accommodates up to eighteen cells. A built-in movement mechanism moves the cells past the light beam.

In other recently developed systems, fiber-optics are being used in conjunction with UV scans to conduct in-situ absorption measurements---that is, measurements taken directly in the sample containers of either dissolution test equipment or sample analysis equipment. Fiber optic cables consist of, for example, glass fibers coaxially surrounded by protective sheathing or cladding, and are capable of carrying monochromatic light signals. A typical in-situ fiber-optic method associated with dissolution testing involves submerging a dip-type fiber-optic UV probe

in test media contained in a vessel. A light beam (UV radiation) provided by a deuterium lamp is directed through fiber-optic cabling to the probe. Within the probe, the light travels through a quartz lens seated directly above a flow cell-type structure, the interior of which is filled with a quantity of the test media. The light passes through the test media in the flow cell, is reflected off a mirror positioned at the terminal end of the probe, passes back through the flow cell and the quartz lens, and travels through a second fiber-optic cable to a spectrometer.

For the previously described Varian CARY 50™ spectrophotometer, a fiber-optic dip probe coupler is available to enable in-situ sample measurement methods and effectively replace the need for a sipper accessory. This fiber optic coupler can be housed in the spectrophotometer unit in the place of the conventional sample cell. The coupler includes suitable connectors for coupling with the source and return optical fiber lines of a remote fiber-optic dip probe. The light beam from the light source of the spectrophotometer is directed to the source line of the dip probe, and the resulting optical signal transmitted back to the spectrophotometer through the return line.

Fiber optics have also been employed in connection with sample-holding cells. For example, U.S. Patent No. 5,715,173 discloses an optical system for measuring transmitted light in which both a sample flow cell and a reference flow cell are used. Light supplied from a light source is transmitted through an optical fiber to the sample flow cell, and also through a second optical fiber to the reference flow cell. The path of transmitted light from each flow cell is directed through respective optical fibers toward an optical detector, and is controlled by an optical path switcher in the form of a light selecting shutter or disk.

It is acknowledged by persons skilled in the art that, when working with an array of flow cells, sample cells, cuvettes, probes, and other instruments of optical measurement, and particularly in connection with fiber-optic components, there remains a need for efficiently and effectively routing or distributing light energy to and from such sample containers. This need has been the subject of some developmental efforts.

For instance, U.S. Patent No. 5,526,451 discloses a fiber-optic sample analyzing system in which a plurality of cuvettes each have a source optical fiber and a return optical fiber. A device is provided for selecting a source fiber to receive radiation for passage through a selected sample of one of the cuvettes, and for returning transmitted radiation from the selected cuvette through a selected return fiber to a spectrophotometer. The selection device includes a single rotatable retaining member supporting the respective ends of eight fiber-optic input lines and eight corresponding fiber-optic output lines. The respective ends of the fiber-optic lines are

arranged in a ring around the central axis of the retaining member. The eight input lines define one half of the ring while the eight output lines define the other half. By this arrangement, each input line end affixed to the retaining member has a corresponding output line end affixed in diametrically opposite relation along the ring. Rotation of the retaining member determines which pair of input and output lines are respectively aligned with an input lens and an output lens disposed in spaced relation to the retaining member. A source beam passes through the input lens and into the selected input line at the end supported by the retaining member. The source beam then travels through the input line and into the sample cuvette associated with that particular input line. From the sample cuvette, the transmitted beam travels through the output line associated with the selected input line and sample cuvette. This output line terminates at its end supported by the retaining member. Since this output end is aligned with the output lens spaced from the retaining member, the transmitted beam passes through the output lens and is conducted to the analyzing means of the spectrophotometer.

U.S. Patent No. 5,112,134 discloses a vertical-beam photometric measurement system for performing enzyme-linked immunoabsorbent assay (ELISA) techniques. The system includes a light coupling and transmission mechanism utilizing a cylindrical rotor and a fiber-optic distributor. The mechanism receives light from a light assembly. The cylindrical rotor includes an optical fiber having an input end located at its center and an output end located near the its periphery. As the rotor rotates, the input end of the fiber of the rotor remains stationary with respect to the light assembly, while the output end moves around a circular path. The light output of the fiber of the rotor is received by a fiber optic distributor containing a multiplicity of optical fibers having their respective input ends arranged in a circular array. As the rotor is indexed about its axis, the output end of its fiber can be brought into alignment with successive fibers of the distributor. On the output side of the distributor, the multiplicity of fibers lead to a fiber manifold. The manifold aligns each fiber with a corresponding one of an array of assay sites. A detector board is located below the assay sites. The detector board contains an array of photodetectors corresponding to the array of assay sites. Light from a selected fiber passes through a corresponding assay site, and into a corresponding photodetector of the detector board. As in other systems, this system requires a plurality of photodetectors and is not capable of routing the incident light from each sample well to a single detection means.

U.S. Patent No. 6,151,111 also discloses a vertical-beam photometric system in which a plate carrier sequentially advances an 8 X 12 microplate through a measurement station. Each column of eight wells is scanned by light emitted from a bundle of eight corresponding

distribution optical fibers. Light supplied from a light source passes through a monochromator to a rotor assembly. Each of the eight distribution fibers enables light from the rotor assembly to be sequentially directed by a corresponding mirror vertically through a corresponding aperture, lens, and microplate well, and subsequently into a corresponding photodetector lens. The rotor assembly consists of two mirrors positioned so as to bend light received by the rotor assembly 180 degrees, after which the light can be directed into one of the distribution fibers. The rotor can then be moved into alignment with another distribution fiber.

U.S. Patent No. 4,989,932 discloses a multiplexer for enabling the sampling of a number of different samples. The multiplexer contains a stationary cylindrical outer body and a rotatable optical barrel disposed within the outer body. A primary inlet port is located on one side of the outer body through which light is introduced into the multiplexer. A primary exit port is located on an opposing side of the outer body through which light exits the multiplexer for transmission to an apparatus for optically analyzing a sample. Pairs of ancillary inlet and exit ports are disposed around the cylindrical wall of the outer body, and are oriented radially (or transversely) with respect to the longitudinal axis. The rotatable barrel contains a first mirror and lens associated with the ancillary exit ports, and a second mirror and lens associated with the ancillary inlet ports. A stepper motor is used to rotate the barrel to successively align the mirrors and lenses with a selected pair of ancillary inlet and exit ports. Light transmitted through the primary inlet port along the longitudinal axis of the multiplexer is turned at a right angle by the first mirror, passes through the first lens, and exits the multiplexer through the selected ancillary exit port. From the selected ancillary exit port, the light is transmitted through a fiber-optic bundle to a sample and returns to the multiplexer through the corresponding selected ancillary inlet port. From the selected ancillary inlet port, the light passes through the second lens, is turned at a right angle by the second mirror, and exits the multiplexer along the longitudinal axis. Other pairs of ancillary inlet and exit ports can be selected by rotating the barrel. In another embodiment disclosed in this patent, incoming light is received by an optical rod that has an angled mirrored surface at its end. Rotation of the rod by a stepper motor positions the angled mirrored surface to direct the light into a selected fiber-optic bundle.

U.S. Patent No. 5,804,453 discloses a system in which a fiber-optic biosensor probe is inserted into a test tube. The probe receives a light beam from a light source and sends a testing signal to the photodetectors of a spectrometer. Time division multiplexing and demultiplexing are implemented to distribute light to and from several biosensors. Switching among inputs and outputs is controlled by an input control signal provided by an electronic clocked counter.

U.S. Patent No. 5,580,784 discloses a system in which a plurality of chemical sensors are associated with several sample vials and arranged between a light source and a photodetector. Optical fibers are used to direct radiation into each sensor, as well as to direct emissions out from the sensors. A wavelength-tunable filter is combined with an optical multiplexer to direct radiation serially to each sensor through the fibers.

In view of the current state of the art, there is a continuing need for improved means for efficiently and effectively routing or distributing light energy to and from sample testing sites. It would be therefore be advantageous to provide a fiber-optic channel selection apparatus that utilizes mechanical components to effect indexing among several optical input and/or output channels in an efficient and controlled manner without the need for costly optics-based switching components. In particular, it would be advantageous to provide an apparatus that enables analysis of multiple samples using only a single light source and a single detection means. Such an apparatus should be designed to minimize light loss and be compatible with a wide range of optical-based measurement systems. The present invention is provided to address these and other problems associated with the prior art.

### SUMMARY OF THE INVENTION

The present invention provides a mechanical, rotary fiber-optic multiplexer (and demultiplexer) apparatus for selecting channels through which a beam or pulse of light is routed in an indexing manner. The apparatus comprises one, two, or more rotary indexing devices. One of the rotary indexing devices demultiplexes a beam of light by distributing the light from a single, common outgoing or source line into a selected one of a plurality of outgoing or source channels. The selection is accomplished by rotating the demultiplexing device into a position at which the common outgoing or source line can optically communicate with the selected outgoing channel. The other rotary indexing device, when employed in certain embodiments of the invention, multiplexes a beam of light for transmission into a single incoming or return line by selecting a selected one of a plurality of incoming or return channels. The selection is accomplished by rotating the multiplexing device into a position at which the common incoming or return line can optically communicate with the selected incoming or return channel. In other embodiments, each incoming or return line is optically aligned with a signal receiving means such as a photodetector, thereby eliminating the need for the second rotary indexing device and the common incoming or return line.

When two such rotary devices are provided in this manner, they are mechanically interfaced in a preferred embodiment so that rotation of one device concurs with rotation of the other device, with the result that the selection of a certain channel of the one device concurs with the selection of a corresponding channel of the other device. For instance, if each device includes twelve channels and thus twelve index positions, the selection of the channel at index position 1 of the one device simultaneously results in the selection of the channel at index position 1 of the other device.

According to one embodiment of the invention, each rotary device comprises two fixed components (i.e., first and second fixed components), a rotary component, and one or more bearings providing an interface between the fixed components and the rotary component. The rotary component is interposed between the two fixed components. Each fixed component faces a respective end of the rotary component. One of the fixed components (e.g., the first fixed component) has an optical aperture at its axial center. The other fixed component (e.g., the second fixed component) has a plurality of optical apertures oriented in a circular arrangement about its axial center. The number of optical apertures in the circular arrangement corresponds to the number of optical channels selectable by the apparatus of the invention. The rotary component has a light guiding path such as an optical fiber having one end located at the axial center of the rotary component and another end located radially outward with respect to the axial center. The centrally located end of the optical fiber of the rotary component is separated from the centrally located optical aperture of the first fixed component by a very small air gap. The offset end of the optical fiber of the rotary component is likewise separated from the plurality of optical apertures of the second fixed component by a very small air gap. These air gaps optimize light transmission while minimizing light loss, and avoid the necessity of using expensive additional optical components to couple the respective apertures and fiber ends of the fixed and rotary components. Indexed rotation of the rotary component with respect to the second fixed component results in selective coupling between the offset end of the optical fiber of the rotary component and each aperture of the second fixed component.

As indicated previously, the two rotary devices included with the apparatus according to at least one embodiment rotate together through a mechanical interface. This interface can be accomplished through a suitable set of gears arranged such that rotation of at least one gear results in rotation of both rotary devices. For example, each rotary device could be provided with its own gear, and each of these gears could be placed in meshing engagement with a third gear. While manual rotation of the third gear in order to rotate the other gears is possible, it is



preferred that the third gear be powered through connection to a motor or similarly automated device. The motor could then be electronically controlled by suitable electronic hardware and/or software. As an alternative to providing gears with each rotary device, gear-like teeth could be formed on respective structures of the rotary devices to eliminate additional gearing. In either case, the rotary devices of the apparatus can be rotated continuously without the need to reverse rotation upon completion of the indexing of each channel provided. For instance, for a twelve-channel apparatus, the sampling interval from index position 1 to index position 2 is equivalent to the sampling interval from index position 12 to index position 1.

In an alternative embodiment of the invention, the first rotary device utilized to select an outgoing channel is provided, but the second rotary device utilized to select an incoming channel is eliminated in favor of suitably collecting a bundle of optical return fibers constituting the incoming channels. The bundle of optical return fibers is disposed at a fixed position at which the ends of the fibers are optically aligned with the receiving window of an optical detection device.

The invention as just described offers advantages when incorporated into any system that includes one or more light sources and one or more devices adapted for receiving light energy from the light sources. In such systems, the mechanical multiplexing/demultiplexing functions realized by the present invention are useful in networking one or more light signals from selected light sources to selected receiver devices. The invention also offers advantages when incorporated into any system that uses optics to route optical signals over several lines or channels between a single light source and a single detector. An example of this latter system is a UV-vis spectrophotometer, which is generally designed to conduct UV scans on prepared samples. It is often desirable to scan a multitude of samples. In accordance with the present invention, each sample can be held in a test vessel or a suitable cell or well, or in any other suitable sample holding or containment means, and fiber-optic input and output lines can be brought into operative communication with each sample test site, or with each probe associated with the sample test site. In this manner, each cell, probe, vessel or test site respectively becomes associated with one of the channels of the apparatus of the invention, and hence becomes associated with the corresponding index positions of the rotary device or devices of the apparatus. Accordingly, the selection of index position 1 of each rotary device, for example, corresponds to the selection of test vessel 1, cell 1, and so on.

According to another embodiment of the present invention, an apparatus for selectively coupling fiber optic lines comprises an optical input selection device, an optical output selection

device, and a rotatable coupling mechanism interconnecting the optical input selection device and the optical output selection device. The optical input selection device is rotatable about a first central axis, and comprises a first input end and a first output end. The first input end is disposed collinearly with the first central axis, and the first output end is disposed at a radially offset distance from the first central axis. The optical output selection device is rotatable about a second central axis, and comprises a second input end and a second output end. The second input end is disposed at a radially offset distance from the second central axis, and the second output end is disposed collinearly with the second central axis. Rotation of the coupling mechanism causes rotation of the first output end and the second input end.

The apparatus advantageously further comprises a plurality of fiber-optic source lines and a plurality of fiber-optic return lines. The plurality of source lines have respective source line input ends fixedly disposed in a circular arrangement, and the plurality of return lines have respective return line output ends fixedly disposed in a circular arrangement. Each source line input end is selectively optically alignable with the first output end of the optical input selection device through incremental rotation of the optical input selection device. Each return line output end is selectively optically alignable with the second input end of the optical output selection device through incremental rotation of the optical output selection device.

The optical input selection device and optical output selection device can be structured with rotary and stationary elements as described hereinabove.

In a specific implementation of this embodiment, the optical input selection device provides an optical path between the first input end and the first output end. In addition, the optical output selection device provides an optical path between the second input end and the second output end. Preferably, the optical paths are provided by first and second internal optical fibers, respectively.

The interconnection of the optical input and output selection devices by the coupling mechanism is advantageously effected by the provision of gearing and/or endless members as described herein. As a result, each rotational index position of the optical input selection device is associated with a corresponding rotational index position of the optical output selection device. Depending on the particular design or construction of the coupling mechanism and its associated components, rotation of the coupling mechanism or a component thereof will result in rotation of both the optical input and output selection devices in either the same rotational direction or in the reverse direction.

According to a further embodiment of the present invention, an apparatus for routing optical signals comprises a base, an optical channel selection device supported by the base, a mounting member supported by the base, and a plurality of fiber-optic return lines. The optical channel selection device is rotatable about a central axis, and comprises an internal optical fiber having an internal optical fiber input end and an internal optical fiber output end. The internal optical fiber input end is disposed collinearly with the central axis, and the internal optical fiber output end disposed at a radially offset distance from the central axis. Each return line has a return line output end fixedly supported by the mounting member.

Preferably, the apparatus also comprises a plurality of fiber-optic source lines having respective source line input ends fixedly disposed in a circular arrangement. Each source line input end is selectively optically alignable with the internal optical fiber output end of the optical channel selection device through incremental rotation of the optical channel selection device.

Preferably, the optical channel selection device comprises a rotary element and a stationary element. The rotary element is rotatable about the central axis, and comprises an input end surface and an opposing output end surface. The internal optical fiber input end is exposed at the input end surface and the internal optical fiber output end is exposed at the output end surface. The first stationary element is disposed adjacent to the output end surface, and has a plurality of circumferentially spaced first stationary element apertures. Each first stationary element aperture is disposed at the radially offset distance from the central axis, and the internal optical fiber output end is alignable with a selected one of the first stationary element apertures through rotation of the rotary element.

The apparatus can also comprise a light source communicating with the internal optical fiber input end, and an optical receiving device aligned with each return line output end. In addition, the apparatus can interface with a plurality of sample test sites. Each sample test site optically communicates with the internal optical fiber end of the optical channel selection device at a selected rotary index position thereof and one of the optical return lines corresponding to the selected rotary index position.

The fiber-optic channel selecting apparatus according to any of embodiments described herein can be directly integrated into the design of an optical-based sample measurement and/or analysis system or instrument, such as a spectroscopic apparatus. An example of a spectroscopic apparatus is a spectrophotometer.

According to a method of the present invention, an optical channel is selected from a plurality of optical channels. An optical channel selecting apparatus is provided that comprises

an input selection device including a first input end and a first output end, an output selection device including a second input end and a second output end, and a coupling mechanism interconnecting the input selection device and the output selection device. The input selection device provides an input path between the first input end and the first output end, and the output selection device provides an output path between the second input end and the second output end. The optical channel selecting apparatus selects a first channel by causing the coupling mechanism to move the first output end to a first input position and the second input end to a first output position. Other channels can be selected by causing the coupling mechanism to move the first output end and the second input end to other input and output positions corresponding to other available channels.

According to another method of the present invention for selecting an optical channel from a plurality of optical channels, an input selection device is provided that comprises an input end, an output end, and an input path defined between the input end and the output end. A plurality of optical return fibers are provided that have respective fiber ends disposed at a distance from an optical receiving device. A first channel is selected by causing the input selection device to rotate the output end to a first position at which the input path is optically coupled with a respective return fiber. Other channels are selected through further rotation of the output end to positions corresponding to other return fibers.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 is a perspective view of a fiber-optic channel selection apparatus provided in accordance with the present invention;

Figure 2 is a side elevation view of the apparatus illustrated in Figure 1;

Figure 3 is a top plan view of the apparatus illustrated in Figure 1;

Figure 4 is a rear elevation view of the apparatus illustrated in Figure 1 showing the interconnection of rotary devices provided in accordance with one embodiment of the present invention;

Figure 5A is a cross-sectional view of a rotary device for distributing a light beam or signal from a single input to one or more fiber-optic channels in accordance with the present invention;

Figure 5B is a cross-sectional view of a rotary device for distributing light beams or signals from one or more fiber-optic channels to a single output in accordance with the present invention;

Figure 6A is a cross-sectional view of an optical input selection device provided with the apparatus illustrated in Figures 1-4, including the rotary device illustrated in Figure 5A;

Figure 6B is cross-sectional view of an optical output selection device provided with the apparatus illustrated in Figures 1-4, including the rotary device illustrated in Figure 5B;

5 Figure 7A is a plan view illustrating either the input side of the optical input selection device illustrated in Figure 6A or the output side of the optical output selection device illustrated in Figure 6B;

10 Figure 7B is a plan view illustrating either the output side of the optical input selection device illustrated in Figure 6A or the input side of the optical output selection device illustrated in Figure 6B;

Figure 7C is a perspective view of either of the optical input selection device illustrated in Figure 6A or the optical output selection device illustrated in Figure 6B;

15 Figure 8 is a schematic diagram of an analytical testing and data acquisition system in which the apparatus or portions thereof illustrated in Figures 1 – 7C is incorporated in accordance with the present invention;

Figure 9 is a schematic diagram of another analytical testing and data acquisition system in which the apparatus or portions thereof illustrated in Figures 1 – 7C is incorporated;

Figure 10A is a front elevation view of a fiber-optic bundle mounting component provided with the system illustrated in Figure 9; and

20 Figure 10B is a cross-sectional side view of the mounting component illustrated in Figure 10A.

## **DETAILED DESCRIPTION OF THE INVENTION**

25 In general, the term “communicate” (e.g., a first component “communicates with” or “is in communication with” a second component) is used herein to indicate a structural, functional, mechanical, optical, or fluidic relationship between two or more components or elements. As such, the fact that one component is said to communicate with a second component is not intended to exclude the possibility that additional components may be present between, and/or operatively associated or engaged with, the first and second components.

30 As used herein, the term “multiplexer” is broadly defined to indicate a system or device that includes a plurality of independent, individual input lines or channels and a single output line or channel (i.e., a common path or bus). One of the input lines can be selected so that its value or signal is transmitted or routed over the output line. Thus, the multiplexer could also be

referred to as a data selector. In addition, the term "demultiplexer" is broadly defined herein as implementing the converse function of the multiplexer. That is, a demultiplexer is a system or device that includes one input line or channel (i.e., a common path or bus) and a plurality of output lines or channels. One of the output lines is selected to receive the value or signal provided by the input line. Thus, the demultiplexer could also be referred to as a data distributor. These terms, as used herein, are therefore intended to have a broader meaning than, for instance, the meanings typically understood by persons associated with the communications or electronics industries, wherein the terms are often restricted to meaning a system in which all elements of a given signal are observed simultaneously. For convenience, the term "multiplexer" or "multiplexing apparatus" as used hereinafter is intended to cover a device or system that includes a multiplexer and/or a demultiplexer.

As used herein, the terms "beam," "pulse," and "optical signal" are intended to be interchangeable to indicate that the present invention is applicable to the transmission of light energy by both continuous and non-continuous methods.

As used herein, the terms "aperture" and "bore" are used interchangeably to denote any opening through which light energy can be transmitted with an acceptable degree of efficiency and an acceptable minimum of light loss. Such an opening can include an optical fiber for these purposes as well. Whether the term "aperture" or "bore" is more appropriate could, for instance, depend on the thickness of the structural body through which the opening runs, but in any case the two terms are considered herein to be interchangeable.

Referring now to Figures 1 - 4, an optical signal multiplexing apparatus, generally designated 10, is illustrated in accordance with the present invention. Multiplexing apparatus 10 comprises an enclosure 12 mounted to a base 14. Two rows of apertures (see Figure 3), generally designated 16 and 18, respectively, are formed on a top surface 12A of enclosure 12. Two corresponding rows of fiber optic cable ferrules or fittings generally designated 21 and 23, respectively, (see Figure 1) are mounted in these apertures 16 and 18. Individual fiber-optic source lines  $OSL_1 - OSL_n$  (where, in the illustrated exemplary embodiment,  $n=8$ ) extend through the respective fittings of row 23 (and apertures 18), and individual fiber-optic return lines  $ORL_1 - ORL_n$  extend through the respective fittings of the other row 21 (and apertures 16). In Figures 1 and 3, only the first pair of optical source and return lines, optical source line  $OSL_1$  and optical return line  $ORL_1$ , are shown. In Figure 2, the respective bundles of optical source lines  $OSL_1 - OSL_n$  and optical return lines  $ORL_1 - ORL_n$  are schematically depicted by large

arrows to indicate generally the direction of optical signals into and out from multiplexing apparatus 10.

Portions of enclosure 12 are removed in Figures 1 - 4 to illustrate the interior components disposed within enclosure 12. The primary operative interior components are two rotary indexing devices. One rotary device is referred to herein as an optical source line selector device, generally designated 80, and the other rotary device is referred to as an optical return line selector device, generally designated 130.

Source and return line selector devices 80 and 130 are situated adjacent to one another and are supported in fixed relation to each other, for example, by two axially spaced mounting blocks 26 and 28 that extend upwardly from base 14. A ferrule or input fitting 31 is connected to an input end of source line selector device 80. A circular array of fittings, generally designated 33, are connected to an output end of source line selector device 80. Another circular array of fittings, generally designated 35, are connected to an input end of return line selector device 130. A ferrule or output fitting 37 is connected to an output end of return line selector device 130. A common source line or input bus IB is connected to input fitting 31, and a common return line or output bus OB is connected to output fitting 37. As just described, each individual fiber-optic source line  $OSL_1-OSL_n$  runs through a corresponding fitting 23 of aperture row 18, and each individual return line  $ORL_1-ORL_n$  runs through fittings 21 mounted to aperture row 16. Although not specifically shown in Figure 1 for clarity, each individual fiber optic source line  $OSL_1-OSL_n$  is connected to a corresponding one of fittings 33 of source line selector device 80, and each individual return line  $ORL_1-ORL_n$  is likewise connected to a corresponding one of fittings 35 of return line selector device 130. As described more fully below, source line selector device 80 functions to select which one of the fiber-optic source lines  $OSL_1-OSL_n$  is optically coupled to input bus IB over a given interval of time. Return line selector device 130 functions to select which one of the fiber-optic return lines  $ORL_1-ORL_n$  is optically coupled to output bus OB over the same interval of time.

As best shown in Figures 3 and 4, multiplexing apparatus 10 further comprises a means for causing both source line selector device 80 and return line selector device 130 to rotate simultaneously and in an indexing fashion. Preferably, the means is provided in the form of a powered mechanism adapted to transfer rotational force through a force transmission mechanism. In the exemplary embodiment illustrated in Figures 1-4, the powered mechanism is a motor 40 (such as, for example, a DC stepper motor) that causes a shaft 42 to rotate through

programmed increments. The transmission mechanism includes an arrangement of gear wheels 45, 47 and 49. Gear wheel 45 is mounted to shaft 42 and thus rotates about the axis of shaft 42. Gear wheel 47 is mounted to source line selector device 80 and rotates about an axis  $L_1$  of source line selector device 80 (see Figure 4). Gear wheel 49 is mounted to return line selector device 130 and rotates about an axis  $L_2$  of return line selector device 130. Gear wheels 47 and 49 are disposed in meshing engagement with gear wheel 45. Accordingly, clockwise rotation of gear wheel 45 results in counterclockwise rotation of both gear wheels 47 and 49. Conversely, counterclockwise rotation of gear wheel 45 results in clockwise rotation of both gear wheels 47 and 49. Moreover, gear wheels 47 and 49 are similarly sized and have the same number of teeth.

As a result, rotation of gear wheel 45 through a given incremental arc length causes rotation of both gear wheels 47 and 49 through another proportional incremental arc length. The arc length through which gear wheel 47 rotates is the same as the arc length through which gear wheel 49 rotates.

As appreciated by persons skilled in the art, multiplexing apparatus 10 can be provided with means for verifying the positions of the various rotating components. For example, primary position verification can be effected by providing an optical encoder (not shown) that is focused on shaft 42 of motor 40. As a secondary mode of position verification, Hall effect sensors (not shown) can be provided to interface with a magnet (not shown) mounted on each gear wheel 47 and 49 respectively associated with source line selector device 80 and return line selector device 130. With respect to each source line selector device 80 and return line selector device 130, each corresponding set of Hall effect sensors would be mounted at each index position, such as by mounting the sensors in a circular array on a separate disks that rotates with corresponding barrel 85 or 135 in parallel with the magnet mounted to corresponding gear wheel 47 or 49.

Referring now to Figures 5A-7C, details of source line selector device 80 and return line selector device 130 are illustrated. Referring specifically to Figure 5A, source line selector device 80 comprises a rotary element or barrel 85 that is rotatable about its central axis  $L_1$ . Barrel 85 includes an outer lateral surface 85A, an input end surface 85B, and an output end surface 85C. Gear wheel 47 is fitted around the periphery of outer lateral surface 85A. Gear wheel 47 is either a separate component or comprises teeth formed around barrel 85. An internal bore 87 extends through the body of barrel 85, and has an input bore end 87A opening at input end surface 85B and an output bore end 87B opening at output end surface 85C. Input bore end 87A is coincident with axis  $L_1$ , and thus the position of input bore end 87A in relation to axis  $L_1$



does not change during rotation of barrel 85. Output bore end 87B, on the other hand, is disposed at a location on output end surface 85C that is offset from axis  $L_1$  by a radial offset distance equal to radius  $R$ . Rotation of barrel 85 about axis  $L_1$  therefore results in rotation of output bore end 87B along a circular path of radius  $R$ , as defined on output end surface 85C with respect to axis  $L_1$ . An internal optical fiber 90 (see Figure 6A) extends throughout internal bore 87. Internal optical fiber 90 terminates at an input fiber end 90A (see Figure 6A) located at input bore end 87A, and terminates at an output fiber end 90B (see Figure 6A) located at output bore end 87B. Thus, input fiber end 90A is coincident with axis  $L_1$  and output fiber end 90B is offset from axis  $L_1$  by radial offset distance (or radius)  $R$ . Rotation of barrel 85 about axis  $L_1$  does not affect the position of input fiber end 90A, but results in a circumferential change in the position of output fiber end 90B with respect to axis  $L_1$ .

Referring to Figure 6A, source line selector device 80 is designed to permit rotational indexing of barrel 85 about axis  $L_1$ . Through this rotational movement, output fiber end 90B can be selectively positioned at one of a plurality of equally spaced index locations around a circumference on output end surface 85C. This circumference is swept out by the conceptual end point of radius  $R$  in relation to axis  $L_1$ . In order to implement source fiber "channel" or line selection, barrel 85 rotates with respect to some type of stationary member that includes a number of fixed-position optical reception points corresponding to the plurality of index locations. In Figure 6A, for example, the channel selection is implemented according to the invention by providing a stationary optical reception member. In the present embodiment, the stationary optical reception member is a bearing sleeve or cap 95 disposed at the output side of barrel 85. A bearing 105 provides an interface between rotatable barrel 85 and stationary bearing sleeve 95. As illustrated in Figure 6A, bearing 105 can be a roller bearing of conventional design that includes an inner ring 105A, an outer ring 105B, and a series of balls 107 contacting the respective, opposing raceways of inner ring 105A and outer ring 105B. As understood by persons skilled in the art, balls 107 typically are interposed between inner ring 105A and outer ring 105B and in a circumferentially spaced arrangement through the use of a retaining element (not shown) forming some type of frame, cage, or carriage around each ball 107. Inner ring 105A firmly contacts (such as by press fitting) lateral outer surface 85A of barrel 85, while outer ring 105B firmly contacts at least the inner surface of an annular section 95A of bearing sleeve 95. By this arrangement, inner ring 105A rotates with barrel 85 while outer ring 105B remains in a fixed position with stationary bearing sleeve 95. It will be understood that

bearing 105 could be either a ball bearing or a needle bearing, or some other type of bearing that permits barrel 85 to rotate in a stable manner with respect to bearing sleeve 95. That is, rotatable needle elements could be substituted for balls 107 illustrated in Figure 6A.

In addition to its annular section 95A, bearing sleeve 95 includes a plate section 95B transversely oriented with respect to axis  $L_1$  of source line selector device 80. Plate section 95B is immediately adjacent to output end surface 85C of barrel 85. Plate section 95B includes a plurality of apertures 97 (only two of which are shown in Figure 6A) arranged in a circular array of radius  $R$  with respect to axis  $L_1$ . These apertures 97 constitute the previously described fixed-position optical reception points. The actual number of apertures 97 corresponds to the number of indices at which output fiber end 90B of internal optical fiber 90 can be selectively positioned, and accordingly corresponds to the number of individual optical channels or lines into which an optical signal traveling through internal optical fiber 90 from input fiber end 90A can be selectively directed through output fiber end 90B. The specific number of apertures 97 (and hence the specific number of individual optical channels and index positions) will depend on the number of test sites to which optical source signals are to be sent. Besides the test sites that contain analytical samples, one or more of these test sites could hold reference or control samples (e.g., sources for obtaining blank or standard measurement data). In the example shown in Figure 7B, plate section 95B of bearing sleeve 95 includes an array of eight apertures 97 to handle eight separate optical channels or lines. It will be understood, however, that more or less apertures 97 could be provided, again depending on the number of separate optical channels.

The specific provision of bearing 105 and bearing sleeve 95, in the arrangement and design illustrated in Figure 6A, ensures that any light loss from the light conducting components of source line selector device 80 is negligible. The size of the air gap between output end surface 85C of barrel 85 and plate section 95B of bearing sleeve 95 is preset to provide optimal light transmission. Annular section 95A and plate section 95B of bearing sleeve 95 cooperatively form a shoulder around bearing 105 and output end surface 85C to prevent light losses. In furtherance of the purpose of preventing light loss in this particular arrangement, it is preferable that the axial edges of inner ring 105A and outer ring 105B of bearing 105 facing plate section 95B of bearing sleeve 95 be substantially flush with output end surface 85C of barrel 85.

Although source line selector device 80 and its barrel 85 are not expected to encounter axial thrust forces during the operation of multiplexing device 10, source line selector device 80

can further include a second bearing **125** and corresponding bearing sleeve **115** mounted at the input side, as also shown in Figure 6A. The design and arrangement of input-side bearing **125** and bearing sleeve **115** can be similar to those of output-side bearing **105** and bearing sleeve **95**.

Input-side bearing sleeve **115** thus includes an annular section **115A** and a plate section **115B**.

- 5 As one principal difference, however, input-side bearing sleeve **115** includes only one aperture **117** formed in its plate section **115B** (see also Figure 7A). This single aperture **117** is situated coincident with axis  $L_1$  and is immediately adjacent to input fiber end **90A** of internal optical fiber **90**. The inclusion of input-side bearing **125** and bearing sleeve **115** lends stability to the indexing movements of barrel **85** and overall operation of source line selector device **80**, and
- 10 further facilitates the optical coupling of internal optical fiber **90** to input bus **IB** (see Figure 1). Input-side bearing **125** can comprise balls **127** interposed between an inner ring **125A** and an outer ring **125B**.

- Referring to Figure 5B, return line selector device **130** comprises features similar to those of source line selector device **80** although, as shown in Figure 1, the axial positions of the input and output sides of return line selector device **130** are reversed in comparison to those of source line selector device **80**. Specifically, return line selector device **130** comprises a rotary element or barrel **135** rotatable about its central axis  $L_2$ . Barrel **135** includes an outer lateral surface **135A**, an input end surface **135B**, and an output end surface **135C**. Gear wheel **49** is fitted around the periphery of outer lateral surface **135A**. Gear wheel **49** is either a separate
- 15 component or comprises teeth formed around barrel **135**. An internal bore **137** extends through the body of barrel **135**, and has an input bore end **137A** opening at input end surface **135B** and an output bore end **137B** opening at output end surface **135C**. Input bore end **137A** is disposed at a location on input end surface **135B** that is offset from axis  $L_2$  by a radial offset distance equal to radius  $R$ . Rotation of barrel **135** about axis  $L_2$  therefore results in rotation of input bore
- 20 end **137A** along a circular path of radius  $R$  defined on input end surface **135B** with respect to axis  $L_2$ . Output bore end **137B**, on the other hand, is coincident with axis  $L_2$  such that its position in relation to axis  $L_2$  does not change during rotation of barrel **135**. An internal optical fiber **140** extends throughout internal bore **137**. Internal optical fiber **140** (see Figure 6B) terminates at an input fiber end **140A** located at input bore end **137A**, and terminates at an
- 25 output fiber end **140B** located at output bore end **137B**. Thus, input fiber end **140A** is offset from axis  $L_2$  by radial offset distance (or radius)  $R$  and output fiber end **140B** is coincident with axis  $L_2$ . Rotation of barrel **135** about axis  $L_2$  does not affect the position of output fiber end
- 30

140B, but results in a circumferential change in the position of input fiber end 140A with respect to axis  $L_2$ .

Referring to Figure 6B, return line selector device 130 enables rotational indexing of barrel 135 about axis  $L_2$  in a manner analogous to source line selector device 80. Through the rotational movement effected by return line selector device 130, its input fiber end 140A can be selectively positioned at one of a plurality of equally spaced index locations around a circumference of radius  $R$  defined on input end surface 135B. In order to implement return fiber "channel" or line selection, return line selector device 130 includes a stationary bearing sleeve 145 disposed at the output side of barrel 135. As in the case of source fiber selector device 80, barrel 135 rotates with respect to bearing sleeve 145. A bearing 155 provides an interface between rotatable barrel 135 and stationary bearing sleeve 145. Bearing 155 can be provided in the form of a roller bearing that includes an inner ring 155A, an outer ring 155B, and a series of balls 157 or needles according to conventional designs. Inner ring 155A rotates with barrel 135 while outer ring 155B remains in a fixed position with stationary bearing sleeve 145.

Bearing sleeve 145 of return line selector device 130 comprises an annular section 145A coaxially disposed around bearing 155 and a plate section 145B transversely oriented with respect to axis  $L_2$  of return line selector device 130. Plate section 145B is immediately adjacent to input end surface 135B of barrel 135 with an air gap therebetween, which is dimensioned for optimal optical transmission. Annular section 145A and plate section 145B of bearing sleeve 145 cooperatively form a shoulder around bearing 155 and input end surface 135B. This arrangement of bearing 155 and bearing sleeve 145 ensures that any light loss from the light conducting components of return line selector device 130 is negligible. In furtherance of the purpose of preventing light loss in this particular arrangement, it is preferable that the axial edges of inner ring 155A and outer ring 155B of bearing 155 facing plate section 145B of bearing sleeve 145 be substantially flush with input end surface 135B of barrel 135.

Plate section 145B includes a plurality of apertures 147 (only two of which are shown in Figure 6B) arranged in a circular array of radius  $R$  with respect to axis  $L_2$ . These apertures 147 constitute fixed-position optical coupling points between the individual return fibers  $ORL_1$ - $ORL_n$  and input fiber end 140A of internal optical fiber 140. The actual number of apertures 147 corresponds to the number of indices at which input fiber end 140A can be selectively positioned, and accordingly corresponds to the number of individual optical channels or lines from which an optical signal can be selectively directed into input fiber end 140A. The specific

number of apertures **147** (and hence the specific number of individual optical channels and index positions) will depend on the number of sites or detection areas from which optical return signals are to be received.

As also shown in Figure 6B, return line selector device **130** can further include a second bearing **175** and corresponding bearing sleeve **165** mounted at the output side. The design and arrangement of output-side bearing **175** and bearing sleeve **165** can be similar to those of input-side bearing **105** and bearing sleeve **95**. Output-side bearing sleeve **165** thus includes an annular section **165A** and a plate section **165B**. Output-side bearing sleeve **165**, however, includes only one aperture **167** formed in its plate section **165B**. This single aperture **167** is situated coincident with axis **L<sub>2</sub>** and is immediately adjacent to output fiber end **140B** of internal optical fiber **140** and, on the other side, to output bus **OB** (see Figure 1). Output-side bearing **175** can comprise balls **177** interposed between an inner ring **175A** and an outer ring **175B**.

Figure 7A illustrates plate section **115B** and single aperture **117** of input-side bearing sleeve **115** of source line selector device **80**. Figure 7B illustrates plate section **95B** and multiple apertures **97** of output-side bearing sleeve **95** of source line selector device **80**. Figure 7C illustrates input-side bearing sleeve **115**, output-side bearing sleeve **95**, and bearings **105** and **125** assembled onto barrel **85** of source line selector device **80**. It will be understood that Figures 7A-7C are likewise representative of the structure of return line selector device **130**, but with the input and output sides reversed. That is, Figure 7A could represent plate section **165B** and single aperture **167** of output-side bearing sleeve **165** of return line selector device **130**, and Figure 7B could represent plate section **145B** and multiple apertures **147** of input-side bearing sleeve **145** of return line selector device **130**. Likewise, Figure 7C can be considered as illustrating input-side bearing sleeve **145**, output-side bearing sleeve **165**, and bearings **155** and **175** assembled onto barrel **135** of return line selector device **130**.

According to another aspect of the invention, Figure 8 illustrates the general features of an analytical testing and data acquisition system, generally designated **200**, in which multiplexer apparatus **10** can advantageously operate. In addition to multiplexer apparatus **10**, analytical testing system **200** comprises a light source, generally designated **210**, a data encoding or analytical signal generating system or arrangement, generally designated **220**, and an optical signal receiving device or system generally designated **230**.

Light source **210** can be any type of suitable continuous or non-continuous optical source. Non-limiting examples include deuterium arc lamps, xenon arc lamps, quartz halogen

filament lamps, and tungsten filament lamps. In one specific example, a pulsed light source such as a xenon flash lamp could be employed to emit very short, intense bursts of light. This type of lamp flashes only when acquiring a data point, as compared to a diode array that exposes the sample to the entire wavelength range with each reading and potentially causes degradation of photosensitive samples. As described in commonly assigned U.S. Patent No. 6,002,477, because it emits light on a non-continuous basis, the xenon flash lamp does not require a mechanical means such as a chopper for interrupting the light beam during measurement of a dark signal. One specific example of a xenon flash lamp that is capable of acquiring eighty data points per second is employed in CARY™ Series spectrophotometers commercially available from Varian, Inc, Palo Alto, California.

Data encoding or analytical signal generating system 220 can comprise any device or system adapted to contain and expose one or more samples to the light energy supplied by light source in order to encode information about that sample as the light passes through the sample and the sample is irradiated. For example, data encoding system could constitute an array of test sites  $F_1-F_n$  such as sample measurement and/or holding sites. These test sites  $F_1-F_n$  can be defined by a variety of sample measurement/containment components, such as solid sample holders, sample containers or cells, test vessels, flow cells, tanks, pipes, the wells of a quartz microtitre plate or similar microcells capable of transmitting light, and specially designed fiber-optic probes.

Signal receiving device or system 230 could be any type of instrument or system of instruments adapted to receive and process the optical signals supplied by data encoding device 220. The specific property of the sample substance to be analyzed will dictate the type of equipment or instrumentation used to analyze samples taken from, for example, test vessels. Moreover, the various components comprising signal receiving device 230 will depend on the type of analytical signal to be measured and detected. If the desired analytical signal is the intensity of light radiation absorbed by analytes at each test site  $F_1 - F_n$ , absorbance values can be calculated in order to determine the concentration of the target substance (i.e., the analyte of interest). For this purpose, signal receiving device 230 in Figure 8 can comprise a UV-vis spectrophotometer. The invention, however, is not limited to any specific design of spectrophotometer. Possible configurations for the spectrophotometer include those that utilize single detectors or multi-channel detectors, those that are adapted to perform single-beam or double-beam measurements, those that are adapted to perform horizontal-beam or vertical-beam measurements, and those that can perform measurements of fixed wavelength or of the entire

absorption spectra for the sample. Moreover, for the purpose of the present disclosure, the terms “signal receiving device or system” and “sample analyzing system” are intended to encompass any analyzing equipment compatible with the systems and methods described herein. Such equipment may include, but is not limited to, HPLC, spectrometers, photometers, spectrophotometers, spectrographs, and similar equipment. In the case of a spectrophotometer, signal receiving device **230** typically includes light source **210**, a wavelength selector or similar device, a radiation detector such as a photoelectric detector or transducer, a signal processor, and a readout device.

Referring to the schematic depiction of analytical testing and data acquisition system **200** illustrated in Figure 8, light source **210** optically communicates with source line selector device **80** of multiplexing apparatus **10** via input bus **IB**, and optical signal receiving device **230** optically communicates with return line selector device **130** via output bus **OB**. In the present embodiment, data encoding system **220** comprises a set of sample measurement components or test sites  $F_1 - F_n$  (e.g., flow cells, sample cells, test vessels, or the like), each of which is adapted to contain or provide a target for a sample to be analyzed. Source line selector device **80** optically communicates with sample measurement components  $F_1 - F_n$  via the set of optical source lines  $OSL_1 - OSL_n$ , respectively, and return line selector device, **130** optically communicates with sample measurement components  $F_1 - F_n$  via a set of optical return lines  $ORL_1 - ORL_n$ , respectively. For clarity, only four each of optical source lines  $OSL_1 - OSL_n$ , sample measurement components  $F_1 - F_n$ , and optical return lines  $ORL_1 - ORL_n$  are shown in Figure 8. By this arrangement, each sample measurement component  $F_1 - F_n$  can receive an incident light input of an initial intensity  $P_0$  from light source over a corresponding optical source line  $OSL_1 - OSL_n$ , and subsequently transmit a light output of an intensity  $P$  to optical signal receiving device for processing and readout over a corresponding optical return line  $OSL_1 - OSL_n$ . As described previously, respective internal optical fibers **90** and **140** of source and return line selector devices **80** and **130** are rotatably indexed in mutual synchronization. As a result, the selection of optical source line  $OSL_1$ , for example, to carry the source signal from internal optical fiber **90** of source line selector device **80** to sample measurement component  $F_1$  concurs with the selection of optical return line  $ORL_1$  to carry the attenuated signal transmitted from sample measurement component  $F_1$  to internal optical fiber **140** of return line selector device **130**.

Referring back to Figure 3, some of the features of the system described with reference to Figure 8 are schematically shown in operative communication with multiplexing apparatus 10. Light source 210 optically communicates with input bus IB, and output bus OB optically communicates with signal receiving device 230. Sample measurement component F<sub>1</sub> optically communicates with optical source line OSL<sub>1</sub> and optical return line ORL<sub>1</sub>. In addition, sample measurement component F<sub>1</sub> is illustrated in the form of a liquid phase-containing sample holding cell, and accordingly is illustrated as fluidly communicating with a media sample line SL<sub>1</sub> and a media return line RL<sub>1</sub>. As described hereinabove, optical source line OSL<sub>1</sub> is connected to one of fittings 33 of source line selector device 80, and optical return line ORL<sub>1</sub> is connected to one of fittings 35 of return line selector device 130. It will be understood that other sample measurement components F<sub>2</sub> - F<sub>n</sub> can be analogously interfaced with multiplexing apparatus 10 and other corresponding media sample lines and media return lines (not shown).

The operation of sample analysis system 200 with sample cells (e.g., sample cell or flow cell F<sub>1</sub> as shown in Figure 3) will now be described. One or more samples of media are transferred from selected test vessels (which could be, for example, mounted in a dissolution test apparatus or other appropriate media preparation/testing apparatus) through media sample lines (e.g., sample line SL<sub>1</sub> in Figure 3) to corresponding sample cells F<sub>1</sub> - F<sub>n</sub>. After optical measurements are taken, the samples can be, if the system is so configured, returned to the test vessels through media return lines (including return line RL<sub>1</sub> shown in Figure 3). Calibration operations can also be carried out prior to test runs as needed.

Multiplexing apparatus 10 is operated as described with reference to Figures 1 - 7C. Preferably, the movements of multiplexing apparatus 10 are coordinated with the operations of the other elements of sample analysis system 200 under the control of a suitable electronic processing device such as a computer (not shown). Accordingly, source line and return line selector devices 80 and 130 of multiplexing apparatus 10 are initially set to their respective home positions. At the home positions, one of the bundle of optical fiber source lines OSL<sub>1</sub> - OSL<sub>n</sub> is positioned (e.g., at "index position 1") in optical coupling relation with optical input bus IB, and a corresponding one of the bundle of optical fiber return lines ORL<sub>1</sub> - ORL<sub>n</sub> is positioned (e.g., at a corresponding "index position 1") in optical coupling relation with optical output bus OB. In effect, multiplexing apparatus 10 selects the sample measurement component F<sub>1</sub> - F<sub>n</sub> corresponding to the selected index position of source and return selector devices 80 and 130.



To take a measurement of the sample residing in the selected sample measurement component, light source **210** sends a beam of light of intensity  $P_0$  into input bus **IB**. Source line selector device **80** is positioned such that the light is routed into the selected one of the bundle of source lines **OSL<sub>1</sub> - OSL<sub>n</sub>**. This source beam (or pulse) is thus transmitted into the particular sample measurement component **F<sub>1</sub> - F<sub>n</sub>** that corresponds to the selected source line **OSL<sub>1</sub> - OSL<sub>n</sub>** and return line **ORL<sub>1</sub> - ORL<sub>n</sub>**. Light source **210** and the sample residing in the selected sample measurement component can together be considered as a signal generator, in that light source **210** and the sample conjoin to generate the analytical signal in the form of an attenuated beam of light of intensity  $P$  as the beam of light passes through the sample. The analytical signal is transmitted through the selected one of return lines **ORL<sub>1</sub> - ORL<sub>n</sub>** back to multiplexing apparatus **10** and, due to the position of return line selector device **130**, is routed into output bus **OB**. Output bus **OB** transmits the analytical signal to signal receiving device **230** for detection and processing, and the concentration of the measured sample is determined from the value obtained from its measured light absorbance, using calibration curves if necessary.

Within signal receiving device **230**, a wavelength selector is typically provided in the form of a filter or monochromator that isolates a restricted region of the electromagnetic spectrum for subsequent processing. The detector converts the radiant energy of the analytical signal into an electrical signal suitable for use by the signal processor. The signal processor can be adapted to modify the transduced signal in a variety of ways as necessary for the operation of signal receiving device **230** and the conversion to a readout signal. Functions performed by the signal processor can include amplification (i.e., multiplication of the signal by a constant greater than unity), logarithmic amplification, ratioing, attenuation (i.e., multiplication of the signal by a constant smaller than unity), integration, differentiation, addition, subtraction, exponential increase, conversion to AC, rectification to DC, comparison of the transduced signal with one from a standard source, and/or transformation of the electrical signal from a current to a voltage (or the converse of this operation). Finally, a readout device displays the transduced and processed signal, and can be a moving-coil meter, a strip-chart recorder, a digital display unit such as a digital voltmeter or CRT terminal, a printer, or a similarly related device.

As indicated previously, remote flow cells are but one type of means for encoding information that can be processed by signal receiving device **230**. Other examples of sample measurement components are fiber-optic probes, or dip probes, that are designed for insertion directly into a container holding an analyte-containing media. In some applications, the use of dip probes has been a substitute for the removal (and preferably the subsequent return) of

samples from the media container and the transfer of the samples to the sample cell of a spectroscopic or other sample analyzing apparatus.

In addition to the use of sample containment means such as flow cells, dip probes and the like as specified hereinabove, other means and accessories can be employed for generating analytical data in accordance with the invention. For example, instead of absorption probes, reflectance probes can be employed for undertaking reflectance measurements of samples. As appreciated by persons skilled in the art, a typical reflectance probe includes two fiber-optic bundles. One bundle forms a central core and delivers light to the sample. The other bundle surrounds the central core, and collects the light reflected from the sample and returns it to the detector of the associated sample analyzing instrument. Alternatively, a transmission probe can be employed to enable the measurement of solid samples. A typical transmission probe includes two single optical fibers. One fiber delivers light to the sample, and the other collects the light transmitted through the sample and returns the transmitted light to the sample analyzing instrument. The transmission probe is preferably used in conjunction with a sample holder adapted to position the sample for measurement. The nature of the sample (e.g., textile fabrics, sunglasses) dictates the design of the sample holder. Transmittance data can also be acquired from solid samples using an integrating sphere, which is a hollow sphere having an internal surface that is a non-selective diffuse reflector. Integrating spheres are often used to measure the transmission of turbid, translucent, or opaque refractory materials in situations where other techniques are inadequate due to loss of light resulting from the scattering effects of the sample.

Referring back to Figures 1 – 3, while input bus **IB** can be directly coupled to light source **210** and output bus **OB** directly coupled to signal receiving device **230**, this is not a requirement of the invention. The invention contemplates that various accessories and adaptations can be employed, such as those indicated hereinabove, and that multiplexing apparatus **10** can be integrated with existing analytical systems, in accordance with specific applications of multiplexing apparatus **10**. For example, in Figures 1 - 3, multiplexing apparatus **10** can additionally include a fiber-optic coupling unit, generally designated **425**, for routing light beams into and out from fiber-optic cables. Fiber-optic coupling unit **425** comprises an enclosure **431**, fittings **433** and **435** mounted to one or more walls of enclosure **431**, one or more internal optical mirrors **437** and **439** (see Figure 3) disposed within enclosure **431** and positioned at desired angles, one or more apertures **441** and **443** (see Figures 1 and 2) formed in the walls of enclosure **431**, and various types of lenses (not shown) if needed. The input end of input bus **IB** is connected to fitting **433**, and the output end of output bus **OB** is connected to fitting **435**. As

best illustrated in Figure 3, a source signal from light source **210** enters enclosure **431** through aperture **441** (see Figure 1), is reflected off internal mirror **437**, and is diverted into input bus **IB**. A return signal from output bus **OB** is reflected off internal mirror **439** and diverted toward signal receiving device **230** through aperture **443** (see Figure 1).

Referring now to Figures 9, 10A, and 10B, another analytical testing and data acquisition system, generally designated **600**, is illustrated according to another embodiment of the present invention. In some cases, it may be desirable to eliminate either the multiplexing or the demultiplexing feature of the invention. Accordingly, this embodiment provides an alternative multiplexing apparatus, generally designated **10'**, in which return line selector device **130** has been eliminated. Source line selector device **80** functions as described hereinabove. In the present embodiment, multiplexing apparatus **10'** comprises an output bus mounting assembly **630**. Output bus mounting assembly **630** includes an output aperture **632** in which a lens **634** is preferably disposed. Lens **634** can be situated at the terminal end of a cylindrical collar **636** or other suitable means for retaining and collecting optical return lines **ORL<sub>1</sub>-ORL<sub>n</sub>** in a fixed-position bundle. In this embodiment, the bundle of optical return lines **ORL<sub>1</sub>-ORL<sub>n</sub>** collected from, for example, aperture rows **16** or **18** (see Figures 2 and 3) is considered in effect to be a multi-channel output bus for analytical testing system **600**. The bundle of optical return lines **ORL<sub>1</sub>-ORL<sub>n</sub>** could also include an extra test line that is connected to a reference source. In Figure 10A, for example, a total of nine lines are illustrated. For another example, a 16-channel system would have seventeen lines (again assuming one test line were included). Output aperture **632** is optically aligned with the receiving window of a sample detector **SD** or other similar analyzing device or light-receiving component thereof.

In operation, a sample beam from light source **210** is directed through input bus **IB** into the input side of source line selector device **80** in the manner described hereinabove. As also described hereinabove, source line selector device **80** is indexed by motor **40**, shaft **42**, gear wheels **45** and **47**, and other associated components (see Figures 2 and 3) so as to select one of optical source lines **OSL<sub>1</sub>-OSL<sub>n</sub>**. The signal is transferred out from source line selector device **80** through the selected optical source line **OSL<sub>1</sub>-OSL<sub>n</sub>** and associated fitting of one of aperture rows **16** and **18** to the selected sample container of or other type of test site **F<sub>1</sub> - F<sub>n</sub>** of encoding system **220**. The transmitted light beam **P** is then returned through the corresponding one of optical return lines **ORL<sub>1</sub>-ORL<sub>n</sub>**, through one of aperture rows **16** or **18**, to output bus mounting assembly **630** where all optical return lines **ORL<sub>1</sub>-ORL<sub>n</sub>** are bundled at output aperture **632**.

Transmitted light beam **P** emanating from selected optical return line **ORL<sub>1</sub>-ORL<sub>n</sub>** is directed into the window of sample detector **SD**. This window is large enough to receive light from any of the ends of optical return lines **ORL<sub>1</sub>-ORL<sub>n</sub>** bundled at output bus mounting assembly **630**. As an example, the window can be approximately 1 cm<sup>2</sup> in area, and the fiber ends of optical return lines **ORL<sub>1</sub>-ORL<sub>n</sub>** can be positioned approximately 0.5 cm away from the window.

It will be noted that multiplexing apparatus **10'**, in which either source line selector device **80** or return line selector device **130** is eliminated, and either including or not including the other features of spectrophotometer **600**, can be integrated into the various systems of the invention described with reference to Figures 3 and 8 in the place of multiplexing apparatus **10**.

It is therefore seen from the foregoing description that the present invention provides devices and apparatuses that enable the efficient and controlled selection and routing of optical signals and signal paths with minimal light losses. When utilized in conjunction with sample measurement/analysis systems, the embodiments described herein enable high-quality analysis and quantification of analytical samples with decreased effort, expense, and time.

It will be understood that the embodiments described hereinabove can be modified without undue effort to utilize more than one multiplexing apparatus **10** or **10'**, light source **210**, signal receiving device **230** or **SD**, and/or set **F** of sample measurement components.

It will be further understood that various details of the invention may be changed without departing from the scope of the invention. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation—the invention being defined by the claims.